

## Reducing PEM Fuel Cell Hard Freeze Cycles

### Technical Field

This invention relates to reducing hard freeze cycles in PEM fuel cells by means of insulators, which are integral with, inside or  
5 outside of the manifolds, and end plate insulators.

### Background Art

A typical configuration for PEM fuel cells of the type that might be utilized to provide power for electric cars is illustrated in Figs. 1 and 2. Typically, a plurality of contiguous fuel cells 7 are  
10 pressed together into a stack 8 so as to provide good electrical conductivity and no leakage of fluids, by means of tie rods 9 which draw together pressure plates 11 (sometimes referred to as "end plates"). All four sides of the fuel cell stack 8 are fitted with manifolds 12-15 for the various reactant gases, which are sealed to  
15 the stack by means of rubber sealants, gaskets and combinations thereof 18, as is described more fully with respect to Fig. 3 hereinafter. As an example, the manifold 12 may comprise an air inlet and air outlet manifold, the manifold 13 may comprise an air turnaround manifold, the manifold 14 may comprise a fuel inlet and  
20 outlet manifold, and a manifold 15 may comprise a fuel turnaround manifold. In addition, there may be a coolant inlet 20 which would feed an internal coolant manifold (not shown) and a coolant outlet 21, for coolant exiting from the internal coolant manifold. The coolant manifold may also be part of an external manifold  
25 configuration.

In the general case, vehicles must be able to be operated, parked and reoperated in ambient temperatures which fall below the

freezing point of water. It is known that boot strap starts (without preheating) of fuel cell stacks from temperatures of about  $-20^{\circ}\text{C}$  cause a degradation of fuel cell performance, and many boot strap starts from freezing temperatures can render the fuel cell incapable of the performance required to operate a vehicle. In such a case, processes must be performed in order to regenerate the fuel cell and restore its performance.

To isolate a fuel cell from a freezing environment, it is obvious to consider the use of insulation. Typically, in order to prevent a fuel cell stack from reaching  $0^{\circ}\text{C}$  in 60 hours when shut down in a  $-20^{\circ}\text{C}$  ambient, 9 centimeters of fiberglass insulation or 5 centimeters of closed foam insulation would typically be required. Use of common insulation, such as fiberglass, can more than triple the volume which the fuel cell power plant would occupy in a vehicle. When the fuel cell is to be utilized to provide electric power to a vehicle, the space taken up by the fuel cell's power plant is critical. An adequate amount of closed cell foam would approximately double the volume that a fuel cell power plant would occupy in a vehicle. It has been determined that the volumes with insulation described above are intolerable for fuel cell power plants in vehicles.

#### Disclosure of Invention

Objects of the invention include: a fuel cell power plant which will not reach  $0^{\circ}\text{C}$  when inoperative in an ambient environment of  $-20^{\circ}\text{C}$  for about 60 hours; reducing hard freeze cycles of fuel cell power plants; a fuel cell power plant in which the water therein will not reach a hard freeze when the power plant is inoperative in an ambient environment of  $-20^{\circ}\text{C}$  for about 180 hours, or  $-10^{\circ}\text{C}$  for

about 290 hours; improved insulation of a fuel cell stack in a vehicle fuel cell power plant; and improved startup operation of a vehicular fuel cell power plant in subfreezing temperatures.

5 According to the present invention, the reactant gas manifolds on a PEM fuel cell are single or double walled and insulated with vacuum, low thermal conductivity gas, gas-filled panels (GFPs), or vacuum insulation panels (VIPs). According to the invention further, the tie bolts which provide the compressive force between pressure plates of a PEM fuel cell are recessed into the pressure  
10 plates, and the pressure plates are insulated from ambient atmosphere by means of double walled insulator panels, such as chambers which are evacuated or filled with low thermal conductivity gas, VIPs or GFPs.

As an example, a 300 cell 75 kilowatt PEM fuel cell having  
15 normal metal external manifolds for the reactant gases occupies 72 liters. The addition of one centimeter of VIP insulation, in accordance with the invention, increases the volume by 15 liters, to 87 liters. In contrast, to achieve an equivalent thermal resistance, 9 centimeters of fiberglass insulation would be required which would increase the  
20 volume of the same fuel cell stack to an unacceptable 241 liters.

Herein, the summation of the products of (a) number of days at any specific temperature below 0°C times (b) said specific temperature is defined as "minus-degree-days". It is permissible for a significant portion of the water in the stack to freeze; but it is  
25 preferred that not all of the water freeze. Product water can readily be removed from a stack whose temperature is not less than 0°C during a boot strap start. This environmental storage condition is equivalent to 150 minus-degree-days.

Other objects, features and advantages of the present invention will become more apparent in the light of the following detailed description of exemplary embodiments thereof, as illustrated in the accompanying drawing.

5        Brief Description of the Drawings

      Figs. 1 and 2 are simplified and stylized end and side, respectively, elevation views of a PEM fuel cell stack having external reactant gas manifolds which are known to the prior art, and which may be modified in accordance with the present invention.

10        Fig. 3 is a partial, partially sectioned, side elevation view of an external manifold formed of double walled insulation such as a vacuum insulation panel or a panel filled with low thermal conductivity gas, and a similarly composed insulation panel for the fuel cell stack pressure plate.

15        Fig. 4 is a partial, partially sectioned side elevation view of a reactant gas manifold with an integral VIP.

      Fig. 5 is a partial, partially sectioned side elevation view of a reactant gas manifold with an integral GFP.

20        Fig. 6 is a partial, partially sectioned side elevation view of a reactant gas manifold with a VIP disposed internally thereof.

      Fig. 7 is a partial, partially sectioned side elevation view of a reactant gas manifold with a VIP disposed externally thereof.

      Fig. 8 is a partial, partially sectioned end elevation view of a VIP for a fuel cell stack end plate.

25        Fig. 9 is a partial, partially sectioned end elevation view of a GFP for a fuel cell stack end plate.

Fig. 10 is a chart illustrating cool down rate for vacuum insulation panels ranging from ½ centimeter to 5 centimeters in thickness.

#### Mode(s) for Carrying Out the Invention

5                   Referring to Fig. 3, the fuel inlet and outlet manifold 14 of the prior art is modified to provide a reactant gas manifold 14a which has inner and outer walls 30, 31 joined completely around their peripheral edges 33, 34 by a thin wall 35, to form a chamber 36 which may be evacuated or which may contain high molecular weight, low thermal  
10                   conductivity gas, such as argon, krypton or xenon. The manifold 14a is typically formed of resin/fiberglass composite, but it may be made of other materials, including metal.

                  In accord with the invention further, an insulator plate 40 similarly has inner and outer walls 42, 43 which are joined at all of  
15                   their peripheral edges by a thin wall 45, so as to provide a chamber 46 which may contain either a vacuum or a high molecular weight, low thermal conductivity gas. In order to allow for the insulator plate 40, the tie rods 9a are recessed into frustoconical recesses 50 so as  
20                   to present a flush surface for contact with the insulator plate 40.

                  The manifold 14a may be sealed to the fuel cell stack with a  
20                   foam gasket 52, a rubber gasket 54, low viscosity silicone rubber 56 and high viscosity silicone rubber 57, as disclosed in U.S. patent application Serial No. 09/882,750, filed June 15, 2001.

                  Instead of a vacuum or low thermal conductivity gas, the  
25                   chamber 36 of Fig. 3 may contain a vacuum insulated panel (VIP) 59, as shown in Fig. 4. VIPs consist of a filler material 60 called a "core" that is encapsulated in a barrier film 61, which may simply be plastic, or may be a plastic film which is sputter coated with thin metal film,

or may be an aluminum or other metal thin film reinforced by plastic film laminations on each side. The barrier film is evacuated to a pressure between 0.001 Torr (0.0013mbar) and 1.0 Torr (1.3mbar), and thereafter sealed. The details of the VIP are irrelevant to the present invention, and may be chosen to suit any particular implementation thereof. The core may be thermal formed to the shape of the manifold prior to being encapsulated within the barrier film. The manifold may simply comprise the VIP 59 formed in the shape of a manifold, with a puncture resistant film attached to one or both sides of the VIP to provide enhanced structural integrity.

The core material serves three main purposes. First, the core supports the panel walls. Since atmospheric pressure exerts 14.7 psi on the evacuated panel, a one square foot panel would be subject to 2,120 pounds of force. Second, the core material also inhibits the movement of the remaining gas molecules. The smaller the core pore size, the more likely it is that the gas molecules will collide with the branched network of the core material rather than reaching the walls of the VIP. This essentially traps the molecules, and any heat that is conducted to the solid core material would have to pass through a tortuous branch network, where it is mostly dissipated, prior to reaching the walls of the VIP. A core that is based on microporous material, having the smallest pore size, therefore provides the best insulating performance of any solid material. Third, the core materials provide a barrier against heat transfer by radiation and often include special opacifying materials that scatter or absorb infrared radiation. VIPs can presently be provided with thermal conductivities of between 0.002 Watts per meter degree Kelvin ( $W/m^{\circ}K$ ), and 0.008  $W/m^{\circ}K$ .

Referring to Fig. 5, the insulation of a reactant gas manifold 14c may comprise a gas filled panel (GFP) 63 which uses a high molecular weight, low thermal conductivity gas within a hermetic polymer film bag 64 to provide extraordinary thermal insulation.

5 Within the essentially-hermetic barrier provided by the film 64, a cellular structure 65, called a baffle, is filled with the gas. Argon gas provides an effective thermal conductivity of 0.020 W/m°K, krypton gas provides a thermal conductivity of 0.012 W/m°K, and xenon gas provides a thermal conductivity of 0.007 W/m°K.

10 Referring to Fig. 6, a reactant gas manifold 14d may be formed as a single shell of resin/fiberglass composite (or metal, if desired), with a VIP 59 (as described with respect to Fig. 4) disposed on the inside of the manifold 14d. In this case, if required, an additional film may be applied on the inner portion of the VIP 59  
15 so as to provide a surface which is compatible with and impervious to the particular reactant gas within the manifold 14d. Instead of a VIP 59 of the type described with respect to Fig. 4, a GFP 63 of the type described with respect to Fig. 5 may be disposed internally of the manifold 14d.

20 The insulation may be provided externally of a manifold 14e as illustrated in Fig. 7. The insulation may be a VIP 59 described with respect to Fig. 4, or it may be a GFP 63 of the type described with respect to Fig. 5.

25 In Fig. 3, the insulation panel 40 for the end plate 11a is hollow, and the chamber 46 therein is either evacuated or filled with a high molecular weight, low thermal conductivity gas. In Fig. 8, an insulation panel 40a, which may be used with the end plate 11a, contains a VIP 59 of the type described with respect to Fig. 4. The panel 40a may comprise the VIP 59 with a suitable puncture

resistant film 69, such as a resin/fiberglass composite surrounding the VIP 59.

Similarly, an insulation panel 40b shown in Fig. 9 may comprise a GFP 63 of the type described with respect to Fig. 5, surrounded by a film 71 to provide structural integrity. This may comprise a resin/fiberglass composite, or other suitable durable plastic.

Referring now to Fig. 10, cool down rates, for an ambient temperature of  $-20^{\circ}\text{C}$ , are illustrated for a PEM fuel cell stack having an average mass times heat capacity ( $mC_p$ ) of about 16 watt-hours per degree C, and an external area on the order of 9300 square centimeters, insulated according to the invention with vacuum insulation panels of varying thickness, each with a thermal conductivity of  $0.004 \text{ W/m}^{\circ}\text{K}$ . The illustrated fuel cell stack utilizes porous graphite water transport plates as reactant flow fields, and has a water inventory of about 8.0 Kg of water.

In Fig. 10, with insulation having a thickness of 1.0 centimeter, the cell stack assembly temperature reaches  $0^{\circ}\text{C}$  after about 60 hours, but it takes 180 hours to reach a hard freeze, as illustrated by the triangular marks in Fig. 10. A hard freeze occurs when one hundred percent of the water, held within the fuel cell, has solidified. Should the ambient environment temperature be only  $-10^{\circ}\text{C}$ , the cell stack assembly temperature will reach  $0^{\circ}\text{C}$  after about 78 hours, and will reach a hard freeze after about 290 hours.

The choice may be made between volume (due to thickness of the insulation) vs. the length of time desired before the fuel cell stack reaches  $0^{\circ}\text{C}$  or reaches a hard freeze, bearing in mind that insulation of 5.0 centimeters thickness more than doubles the volume required for the fuel cell stack, whereas a one-half centimeter

thickness of insulation according to the invention would yield an increase of about 12% in volume.

5 The time period to reach a hard freeze with one centimeter of VIP 59 corresponds to 150 minus-degree-days or about 180 hours for an ambient temperature of  $-20^{\circ}\text{C}$ .

Thus, the invention may utilize insulation panels having thicknesses ranging from a fraction of a centimeter to five or more centimeters, with thermal conductivities ranging from about  $0.002 \text{ W/m}^{\circ}\text{K}$  to about  $0.020 \text{ W/m}^{\circ}\text{K}$ , and will prevent the fuel cell stack  
10 from experiencing a hard freeze for a period equivalent to 150 minus-degree-days.

The invention may also be utilized with cell stacks which have an ultra-thin current collection sheet associated with an insulation panel, as illustrated in a commonly owned, copending U.S.  
15 patent application, Serial No. (Docket No. C-3144) filed contemporaneously herewith and entitled "Fuel Cell Stack Having Improved Current Collector and Insulator".

Although described with respect to a fuel manifold, the invention incorporates oxidant and other reactant gas manifolds.

20 All of the aforementioned patent applications are incorporated herein by reference.

Thus, although the invention has been shown and described with respect to exemplary embodiments thereof, it should be understood by those skilled in the art that the foregoing and various  
25 other changes, omissions and additions may be made therein and thereto, without departing from the spirit and scope of the invention.

I claim: